



BIOPHYSICS SECTION

Presents

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Ph. D. Candidate

"NON-STANDARD USES OF ECHO-PLANAR IMAGING (EPI)"

Friday, March 22, 1991
4:00 P.M.
Room 2063
ESR Center Library
MACC Fund Research Center

Refreshments Will Be Served

"Non-Standard' Uses of Echo-Planar Imaging (EPI)"

- Introduction to Echo-Planar Imaging

1. Uses
2. EPI advantages and limitations
3. K-space Formalism
4. Performance Parameters
5. Several Pulse-Sequences (unique characteristics)

- Our EPI work so far

1. Hardware
2. Pulse Sequence
3. Reconstruction
4. Specific Problems (with answers and potential answers)

- Presently being Pursued in Conjunction with EPI

1. Diffusion/Perfusion Imaging
2. Selective averaging
3. Retrospective reordering of cardiac cycle without gating

- "Non-standard" uses that will be discussed

2. Flow Imaging (Instant images of laminar and turbulent flow)
4. Dynamic susceptibility-contrast imaging (functional maps)

- Potential Directions to pursue

"Echo-Planar Imaging (EPI): Theory, Method, Uses"

1.Introduction to EPI

2.Our Development of EPI at MCW

3.Our EPI-Related Work

4.Several Uses of EPI

5.Potential Directions to Pursue

Potential Applications of EPI

- Cardiac / Abdominal Imaging
- Dynamic Contrast Studies
- Respiration / Lung / Diaphragm Imaging
- GI / Peristalsis / Swallowing Imaging
- Joint Motion Imaging
- Diffusion / Perfusion Sensitivity
- Laser-Tissue Heating Imaging
- Realtime MR Fluoro (motion in general)
- MR Angiography
- Increased Conventional Imaging Throughput
- Uncooperative patients / children
- Screening and Localization
- Trauma Patient Imaging
- 3D Imaging
- CSF pulsation

Echo-Planar Imaging

Advantages

- 1. Fastest MRI Modality (~128x faster than conv.)**
 - Image time: 20 - 75 ms.
 - High S/N in many cases

- 2. Large image sets of same slice quickly generated for:**
 - dynamic susceptibility-contrast / diffusion / perfusion / flow / motion studies
 - real time studies

Limitations

- 1. Low Spatial Resolution**
 - best so far: 128x256.
 - At MCW: 64x64.
 - with changes, 128x256 can be achieved at MCW.
 - 256x256 not too far off.

- 2. Stringent System Requirements.**
 - Gradients: Strong, Fast, and Homogeneous
 - Extremely Homogeneous B field
 - Negligible eddy currents
 - Data acquisition: Very fast
 - Adaptive Reconstruction
 - Chemical Shift Suppression

K-Space Formalism

[2-D Fourier Imaging in the presence of two time-varying gradients]

$$S(t) = \iint_{-\frac{L_x}{2} \leq x \leq \frac{L_x}{2}, -\frac{L_y}{2} \leq y \leq \frac{L_y}{2}} p(x, y) e^{-(ix k_x(t))} e^{-(iy k_y(t))} e^{-\left(\frac{x}{T_2(x,y)}\right)} dx dy$$

$$\left. \begin{aligned} k_x(t) &= \gamma \int_0^t G_x(t') dt' \\ k_y(t) &= \gamma \int_0^t G_y(t') dt' \end{aligned} \right\}$$

position in k-space.
 as $k \rightarrow \infty \quad S(t) \rightarrow 0$
 $k \rightarrow 0 \quad S(t) \rightarrow \text{max.}$

(Formation of a
gradient-recalled
echo.)

(k in freq. per unit distance)

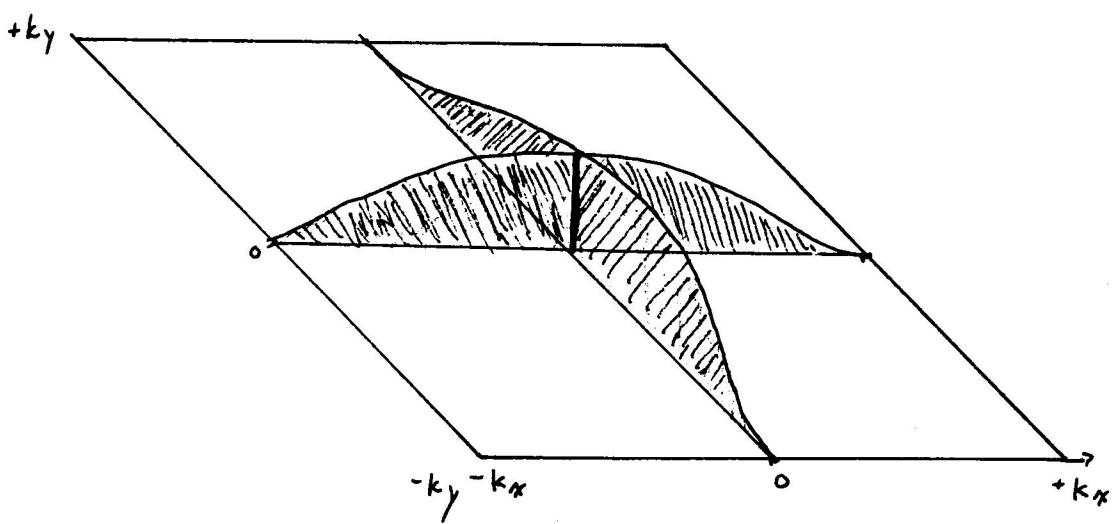
$$\left. \begin{aligned} S(t) &\Rightarrow \text{FID or echo signal intensity} \\ p(x, y) &= \text{spin density distribution} \end{aligned} \right\}$$

$\left[\begin{array}{l} \text{object is real + positive} \\ \text{and at } k=0 \text{ FFT terms } \rightarrow 1 \end{array} \right] \therefore \text{max amplitude}$

$$\left. \begin{aligned} \frac{dk_x(t)}{dt} &= \gamma G_x(t) \\ \frac{dk_y(t)}{dt} &= \gamma G_y(t) \end{aligned} \right\}$$

velocity in k-space.

\therefore as $G \uparrow$ velocity \uparrow
 (ie: quicker scans)
 or
 larger range in k-space



- * Signal \propto k-space position
- * Multiply with T_2 decay function depending upon k-space path.

Performance Parameters

1. Stronger Gradient -> Greater Velocity of k-space

traversal -> For a given time, can go further out in k-space or more densely in k-space -> Increase resolution or FOV.

2. Higher Slew Rate (i.e. Low Inductance & Small) ->

Greater Acceleration in k-space -> Sharper corners in k-space -> More accurate traversal of k-space
-> Nicer for recon.

3. Faster Data Acquisition -> Increased #complex points.

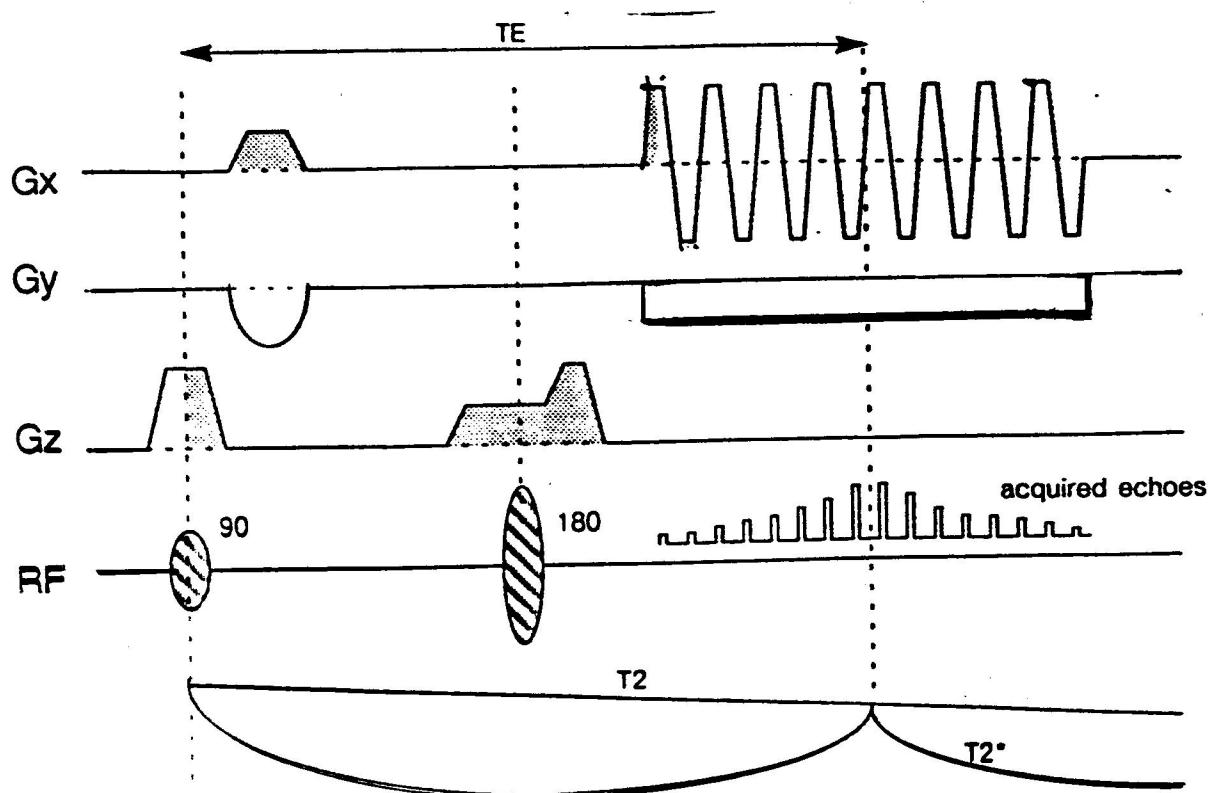
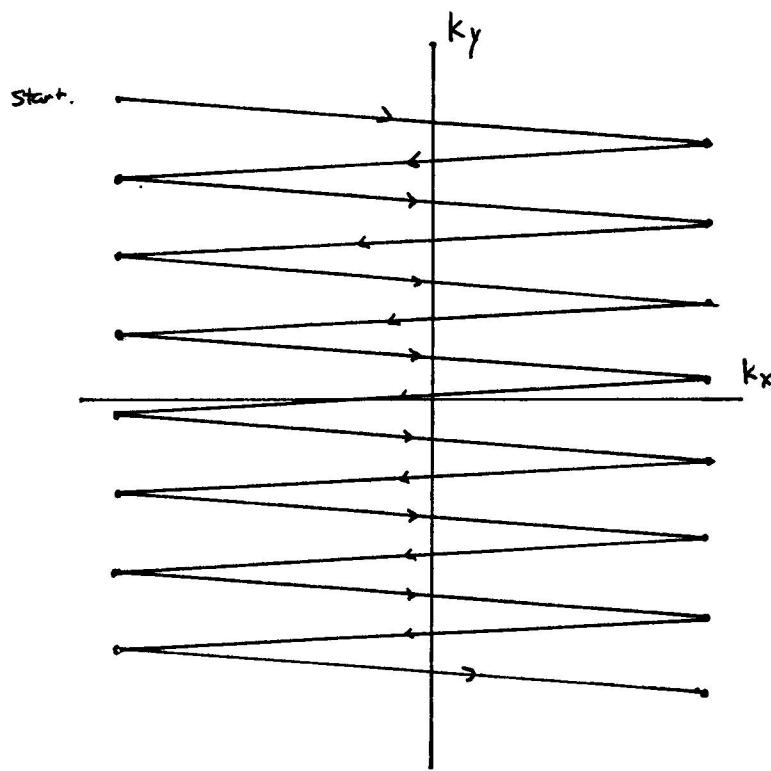
per line -> Increase of FOV at same pixel size.

$$-\rightarrow \text{Decrease S/N : } [\frac{S}{N} \propto (\Delta x \Delta y \Delta z \sqrt{(N_x, N_y) \Delta t N_{EX}})]$$

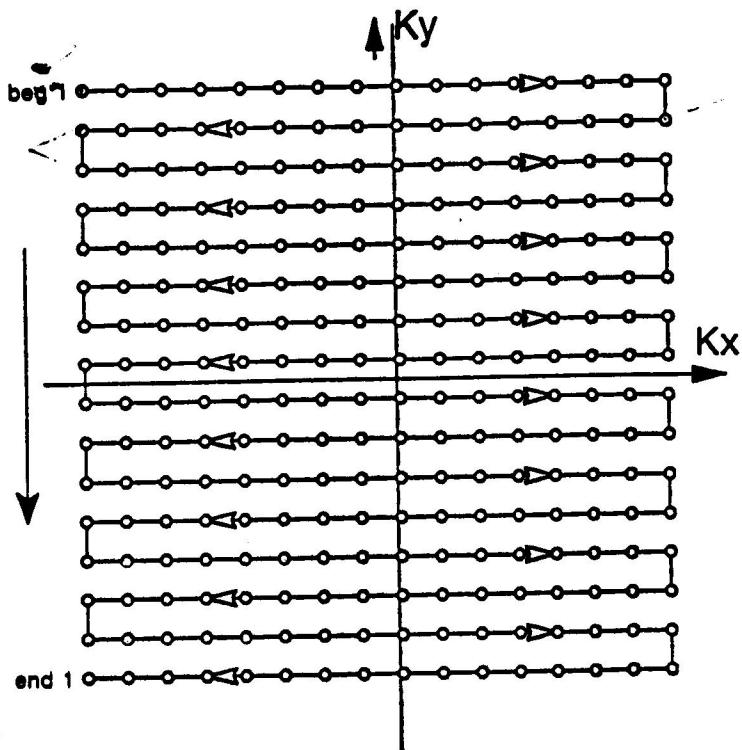
2+3. Both increase image speed which can improve impulse response because of decreased T2 decay down K-space.

1. Gradient Strengths (0.5 G/cm - 22 G/cm)
2. Ramp times (20 us to 1000 us)
3. Acquisition Bandwidths (64kHz - 1MHz)

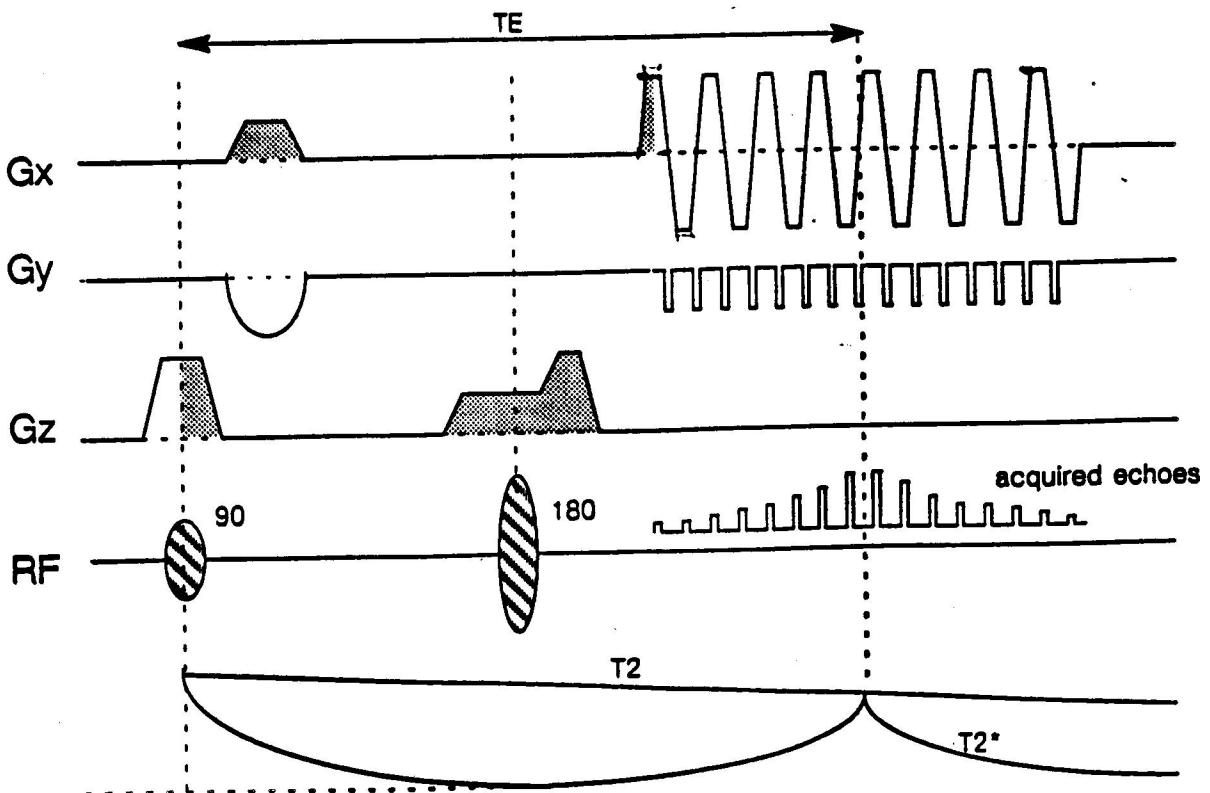
1. Y-grad is constant.
2. Non-uniform k-space trajectory.
3. Utilizes entire echo.



1. Method that we implemented (straightforward).
2. Utilizes entire echo.

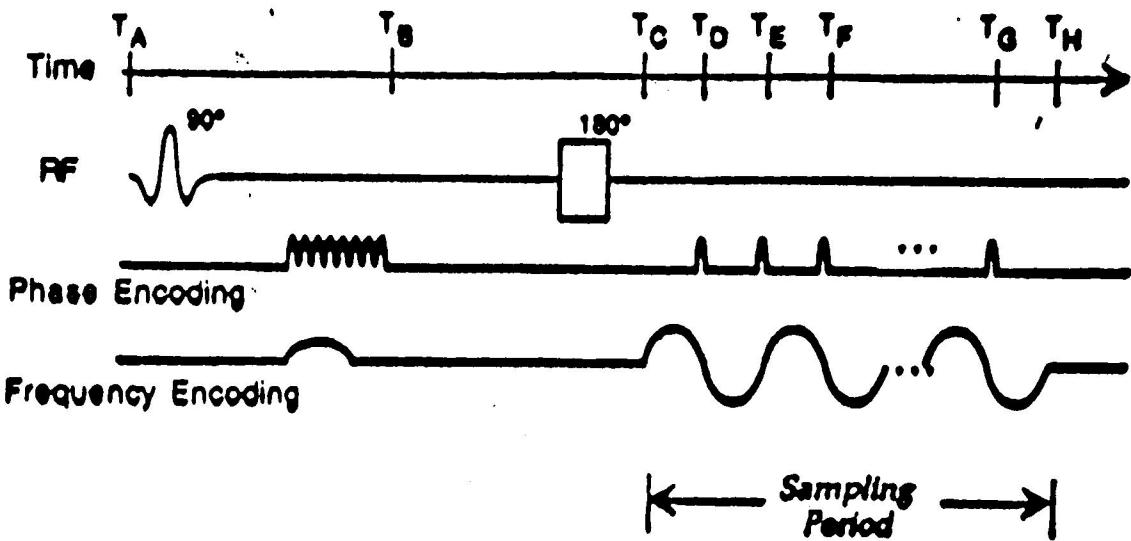
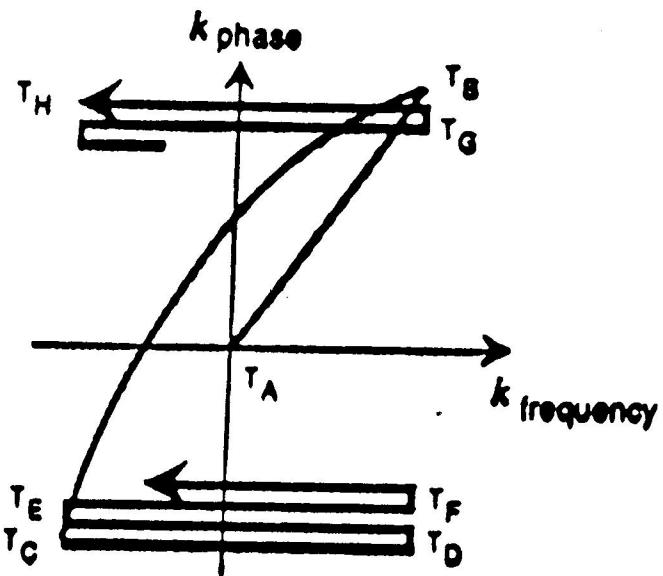


Blipped EPI (with spin echo)



1. Resonates the gradient coils to desired switching frequency.
2. Faster switching using less power than normal grad. amps.

$$f = \sqrt{\frac{1}{Lc}}$$



$$G_x = a \cos[bt] - abt \sin[bt]$$

$$G_y = a \sin[bt] - abt \cos[bt]$$

2. K-space time dependence:

$$k_x = at \cos[bt]$$

$$k_y = at \sin[bt]$$

3. Utilizes FID after initial 90° pulse

4. Because of #3, it is faster.

5. Because of its symmetry:

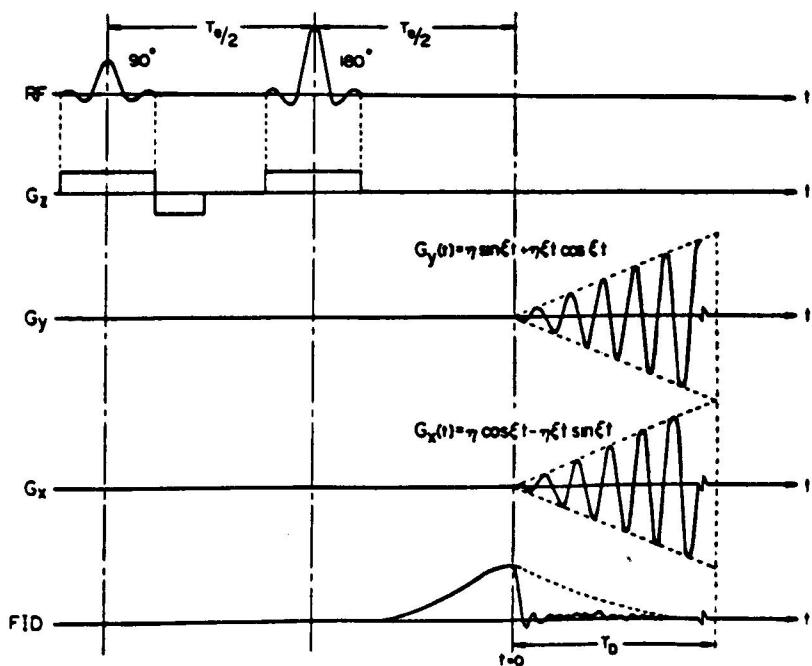
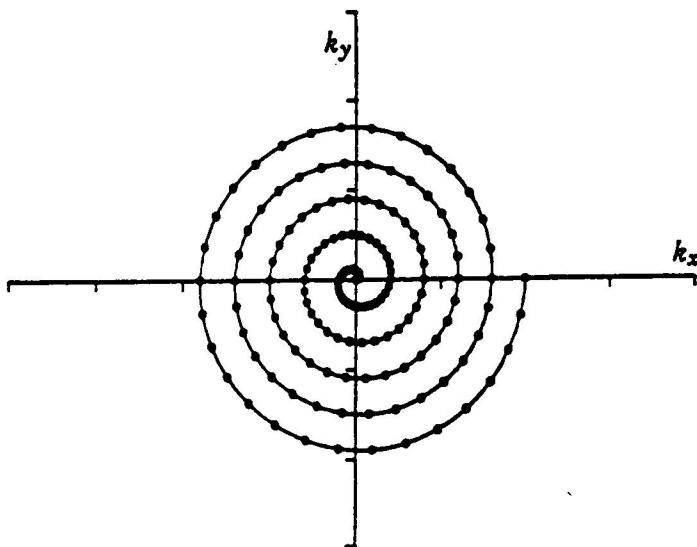
- Circularly symmetric T2 decay .

- better impulse response

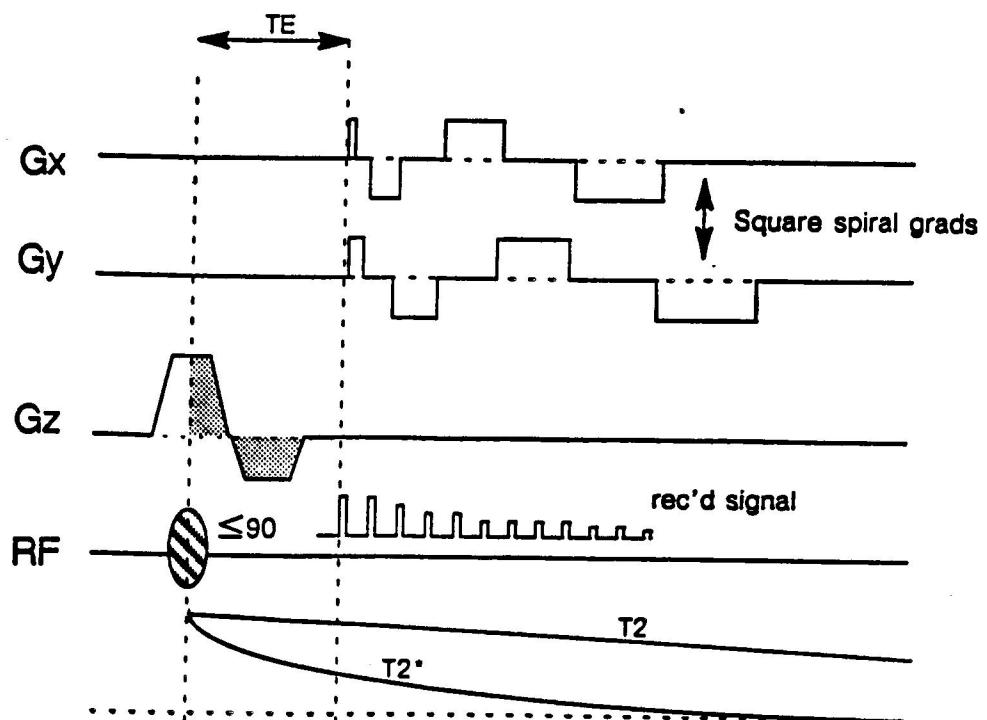
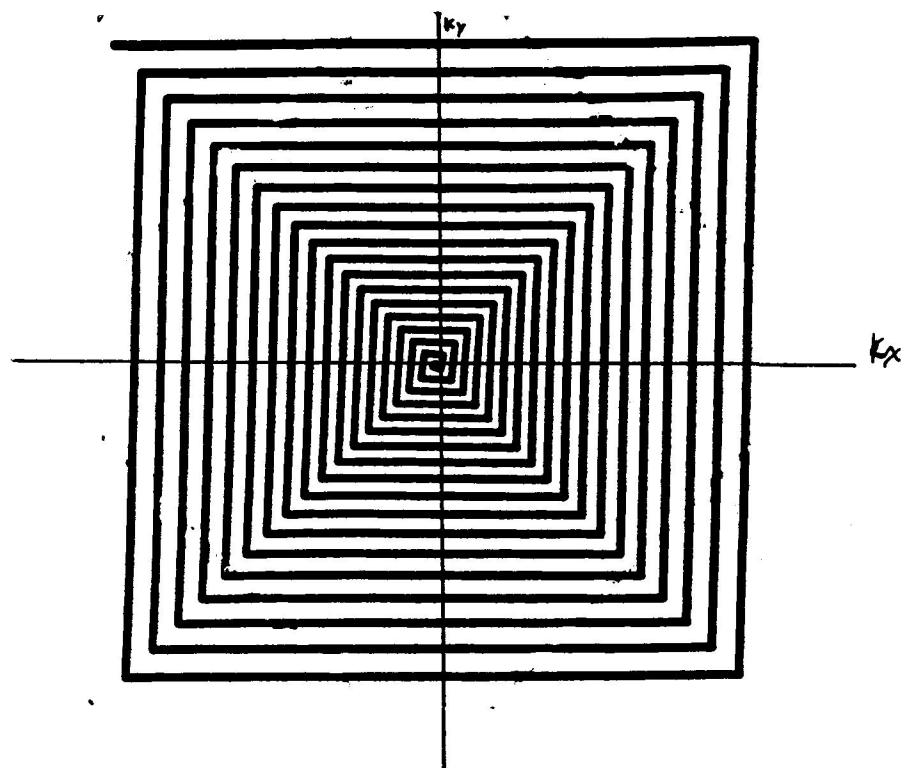
- covers highest energy portion of K-space first

6. Spiral needs to be interpolated to a square grid for 2DFFT.

7. Can also be reconstructed by projection-reconstruction

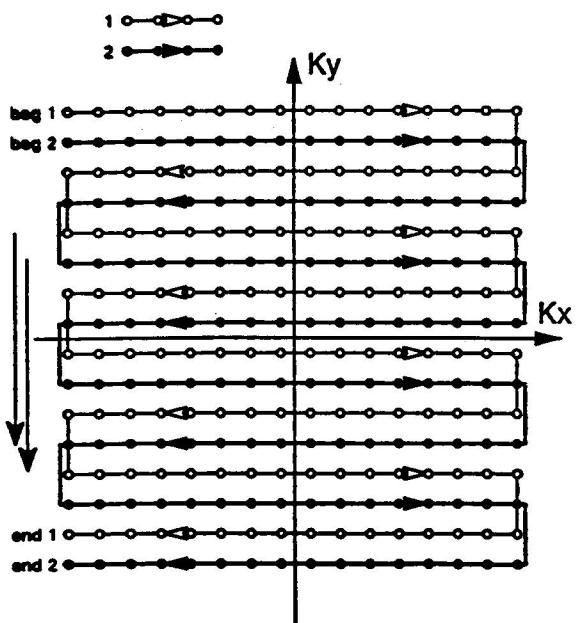


2. Trajectory is discretized.
3. No interpolation necessary. Reordering in recon. is necessary

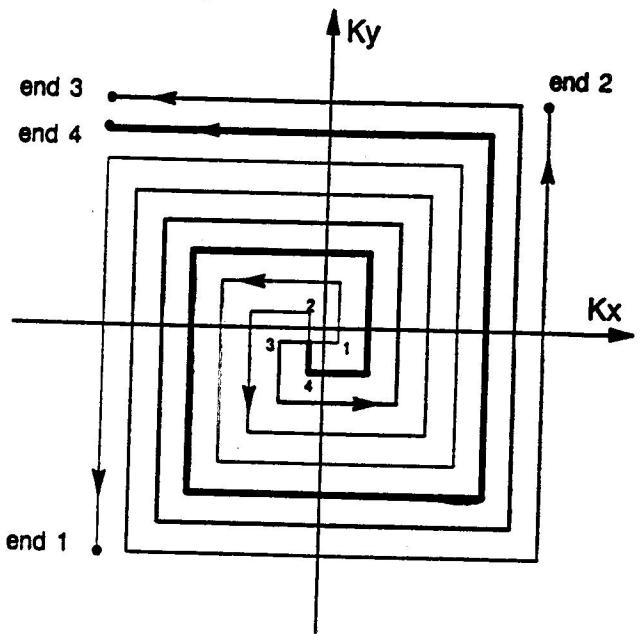


1. ~~Conventional or only a few excitations.~~
2. Slower by #excitations used, but higher resolution per FOV achieved.
3. Can make maximum use of highest power part of k-space.

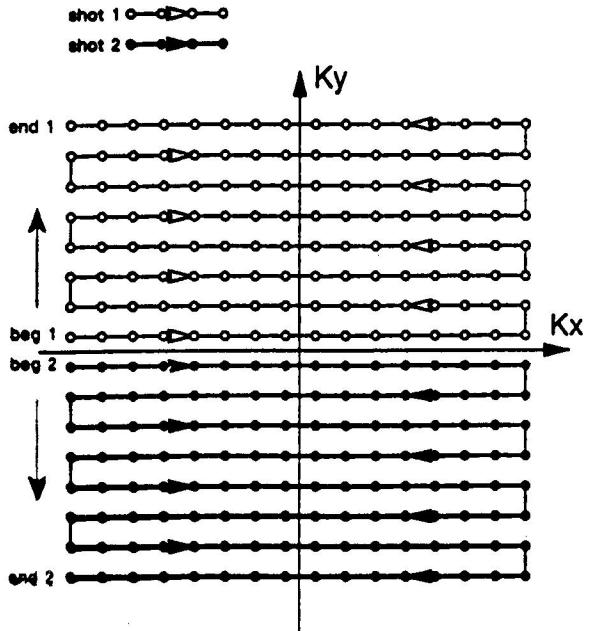
2 shot, "top down" k trajectory



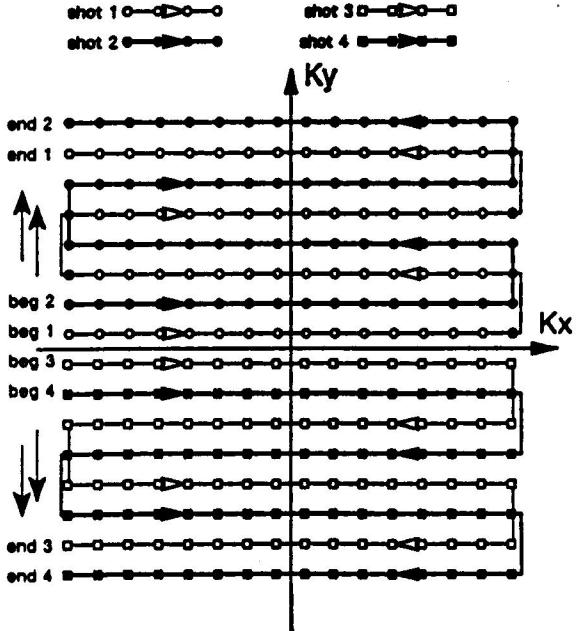
4 shot k trajectory



2 shot, "center out" k trajectory



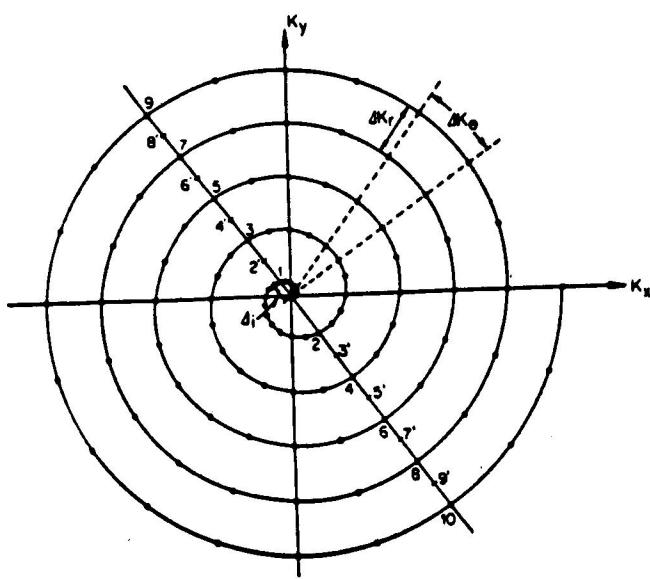
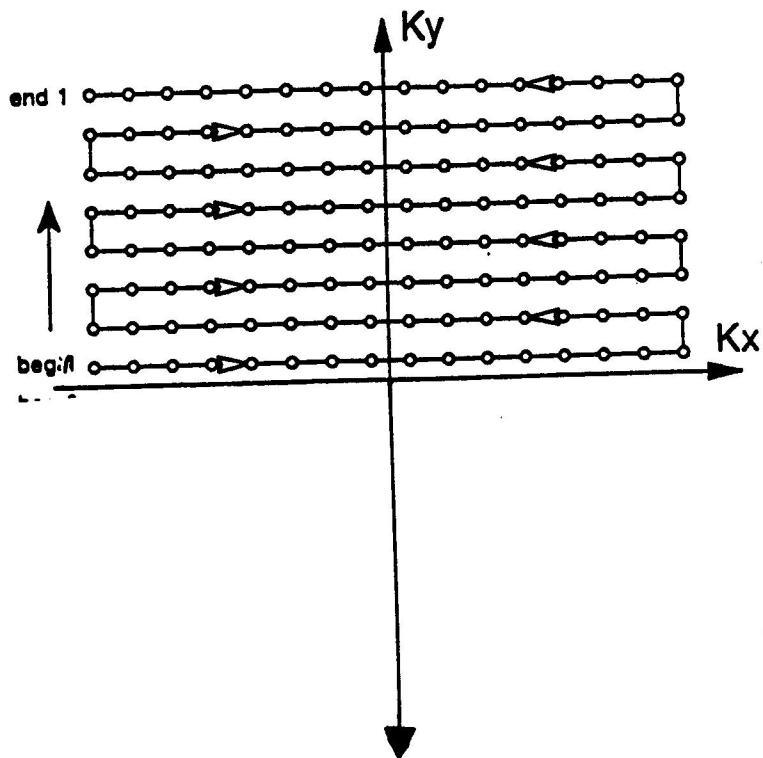
4 shot, "center out" k trajectory



1. K-space trajectory covers half of plane.
2. Makes use of Hermitian symmetry to reconstruct other half with the complex conjugate.
3. Can achieve twice the resolution of full plane scan.

4. Can use only half the time using same resolution
(reduce T_2 effects)

$$\begin{cases} F = I + iQ \\ F^* = I - iQ \end{cases}$$



Our EPI Work So Far

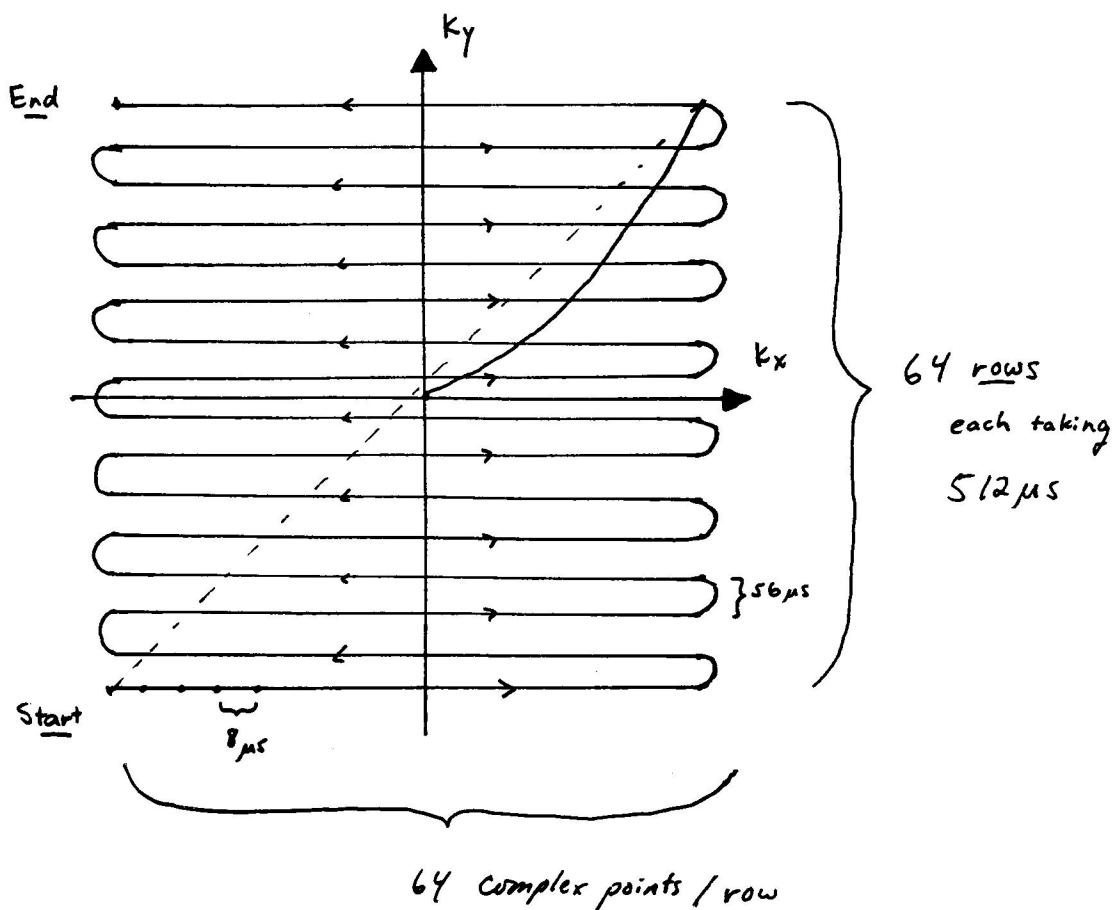
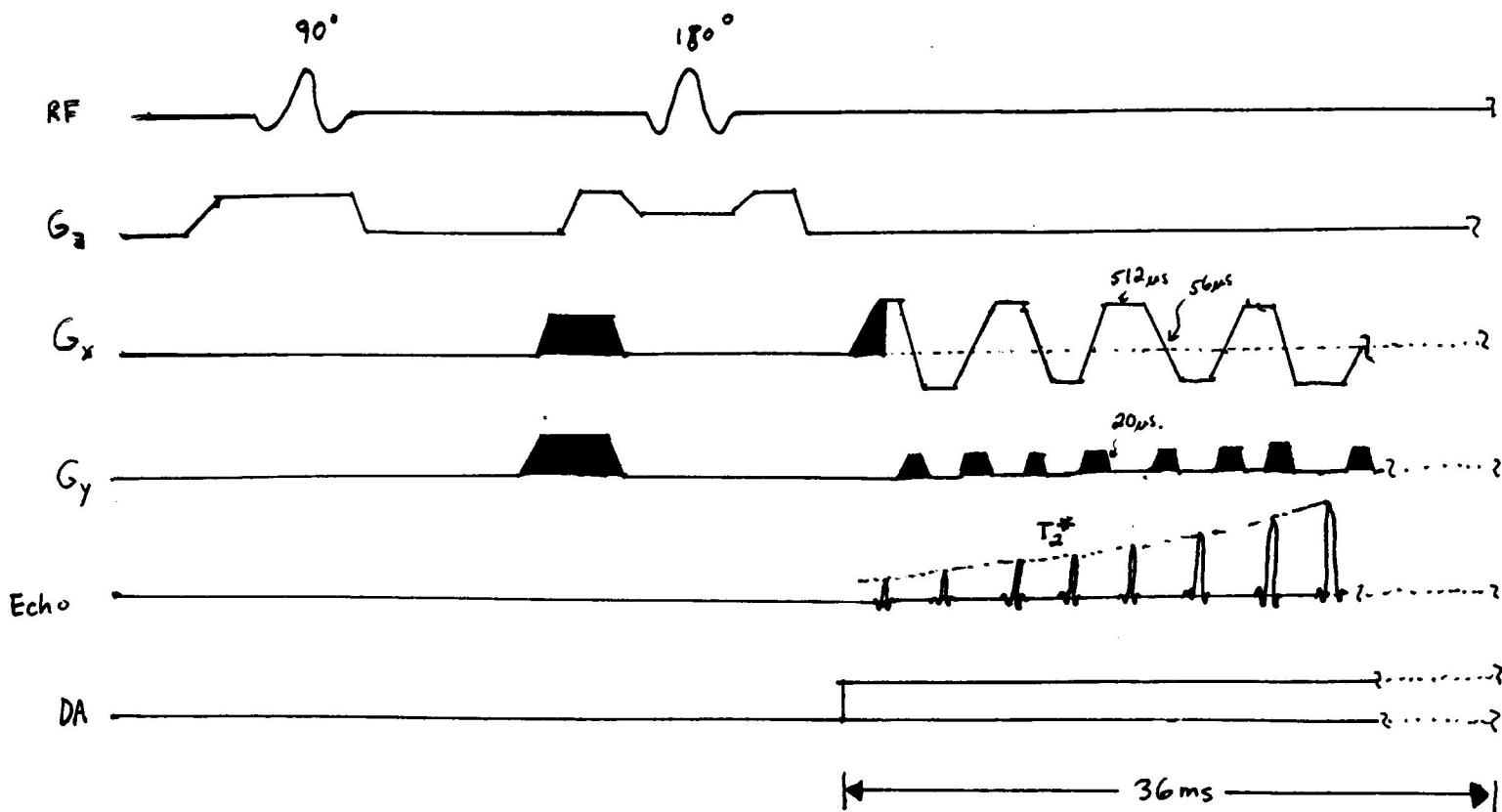
Gradient Coll: • $8 \times 8 \times 22$ G/cm.
•20 us minimum ramp time

Pulse Sequence: •32 Gx cycles -> 64 lines (36 ms)
•63 Gy blips
•Minimum TE of 40 ms
•Total scan time of 60 ms

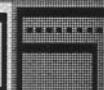
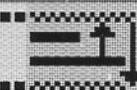
Data Acq: •Full pass filter
•8 us per complex point

Recon: •Collect data, cut points off at ends, switch
and reverse sign of every other row.
•Phase Correction!

Problems: •Phase Errors (variable):
-linear and constant.
•Logic Board Timing.
•Incorrect Gradient Amplitudes.
•Not great gradient profiles.
•Chemical Shift
-Extremely Large in y direction.
-Need fat sat., inversion-recovery, or
spatial-spectral pulse.



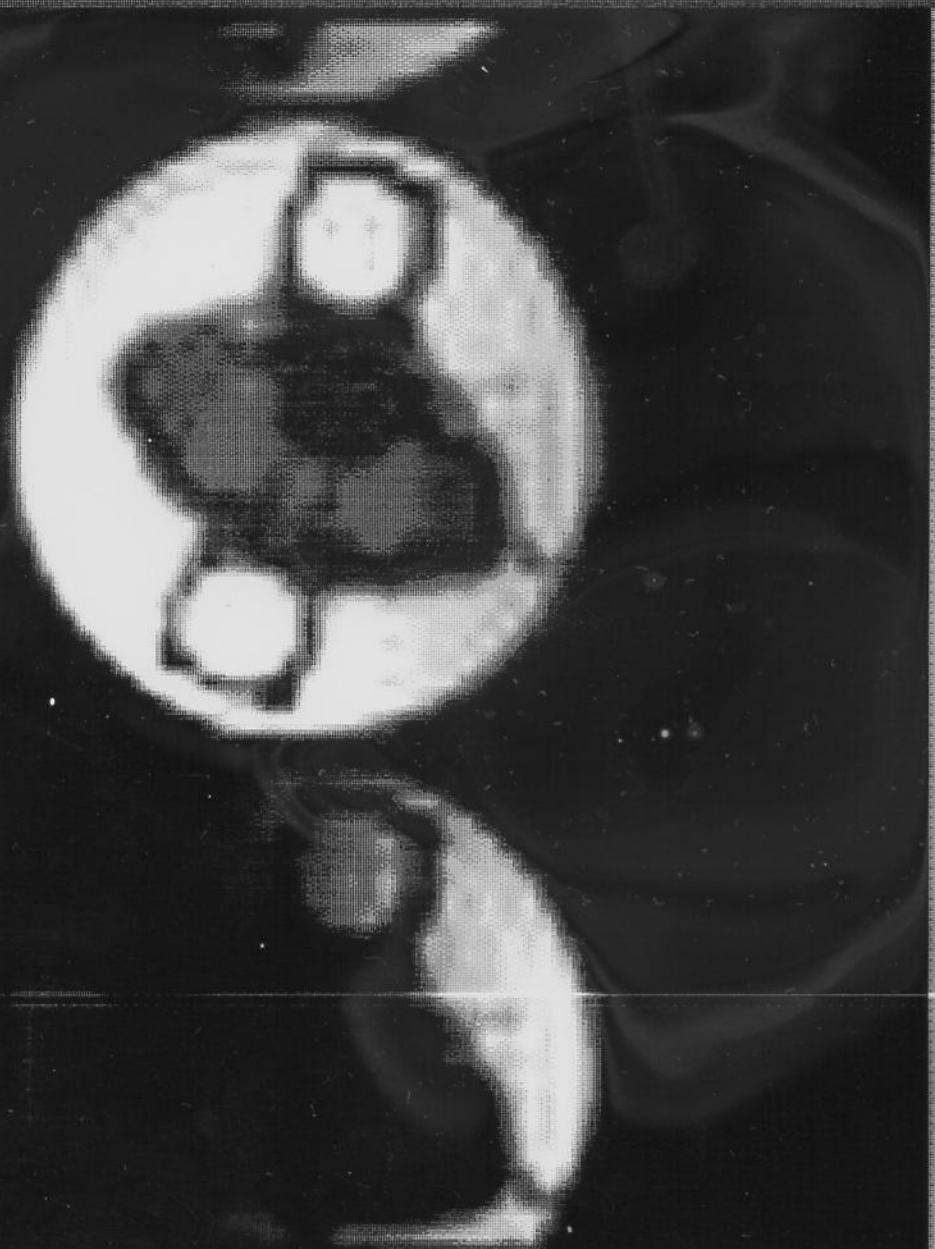
ep40.M



100%

1
8
3
9

0



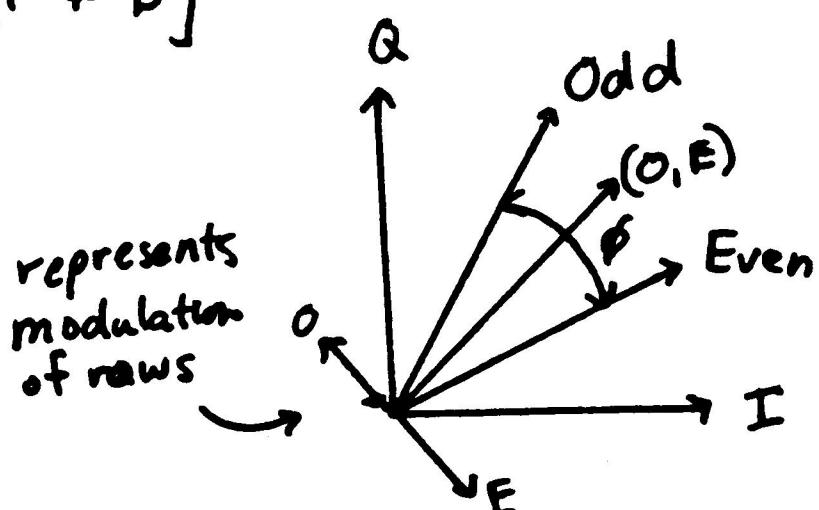
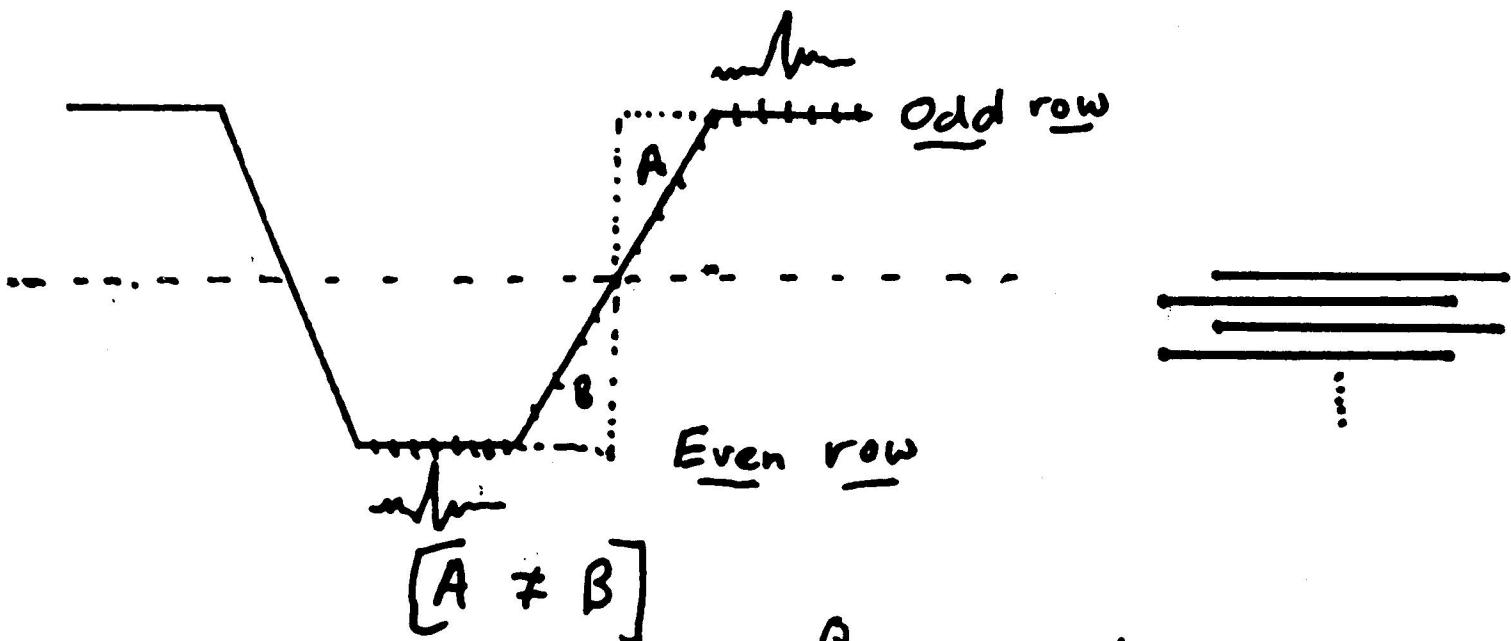
Constant Phase Errors

1. Potential Causes:

- Bad Gradient Profiles (gradient lag time)
- Eddy Currents

2. Description:

- Every pair of echoes has constant phase difference.
- Causes Ghosting (two images):
 - Intensity of correct phase image = $\cos(\phi/2)$
 - Intensity of incorrect phase image = $\sin(\phi/2)$
 - Equal intensity ghosts at 90° phase difference.



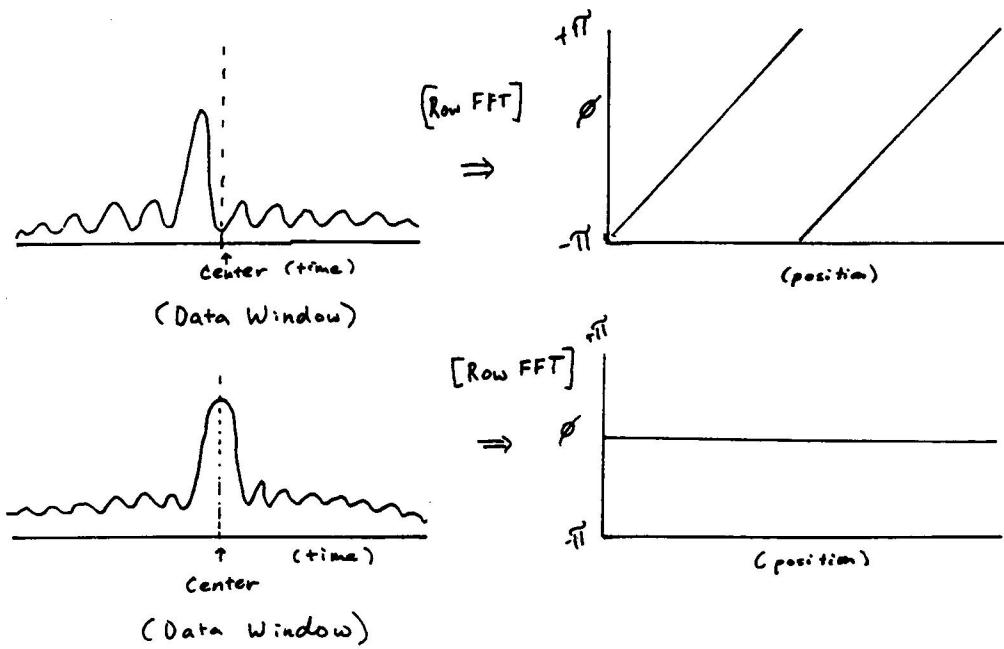
Linear Phase Errors

1. Potential Causes:

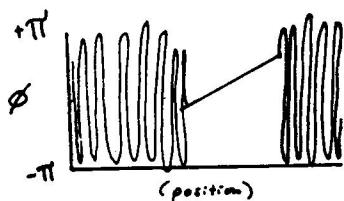
- Incorrect Dephasing Gradients
- Incorrect Data Acquisition Lag.
- Eddy Currents

2. Description:

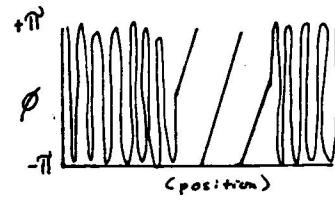
- Each line in K-space has a linear phase twist.
- In raw data, echo not centered in data window.
- Time shift in raw data causes modulation across image.
- Also contributes to Ghosting.



After Row FFT : [Depiction of typical row]



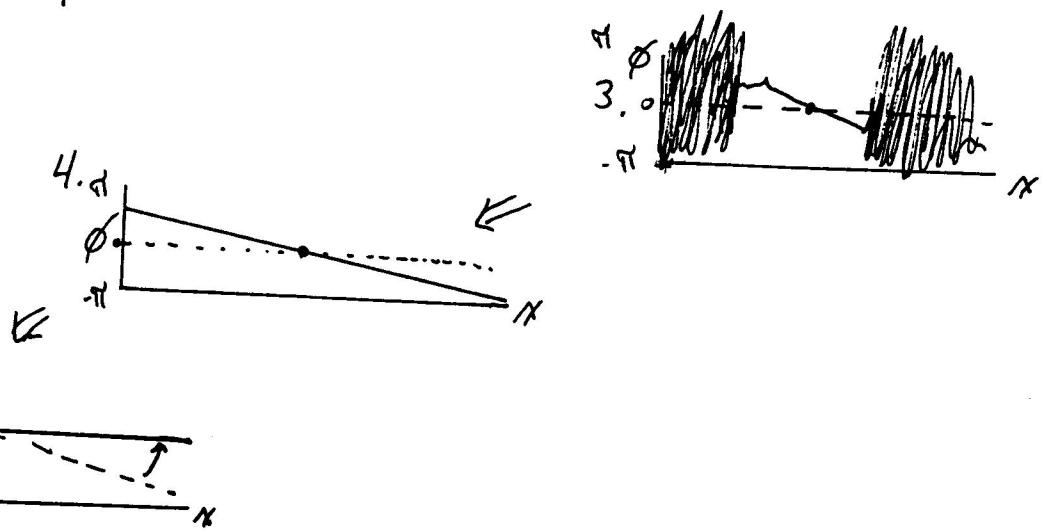
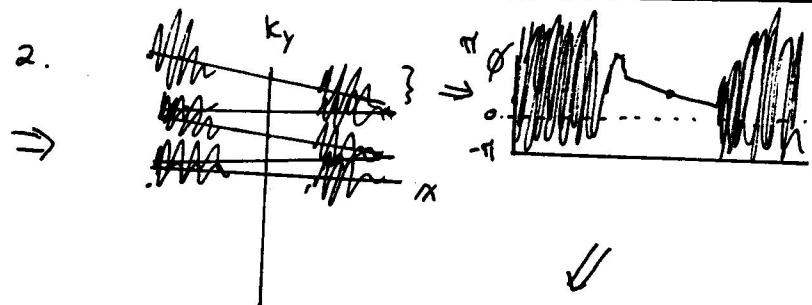
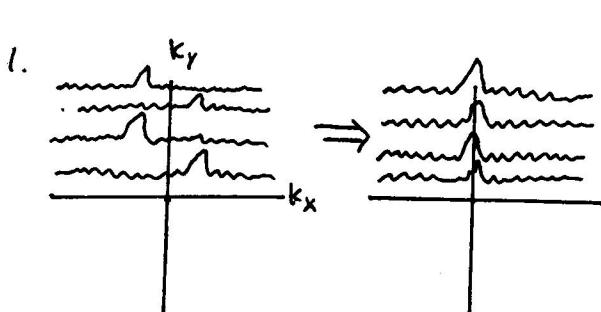
If Shift is Less
Than one



If Shift is More
Than one-half pixel

Phase Correction

1. In raw data, shift each echo to center. L
(accurate to one half pixel = one half phase cycle)
2. Perform row FFT, look at phase of each row.
3. Rotate center to zero phase. C
4. Perform signal intensity weighted linear regression on phase. C
5. Rotate line to achieve zero slope at zero phase. L, C



ep40pc.M

100%

4
5
4

0

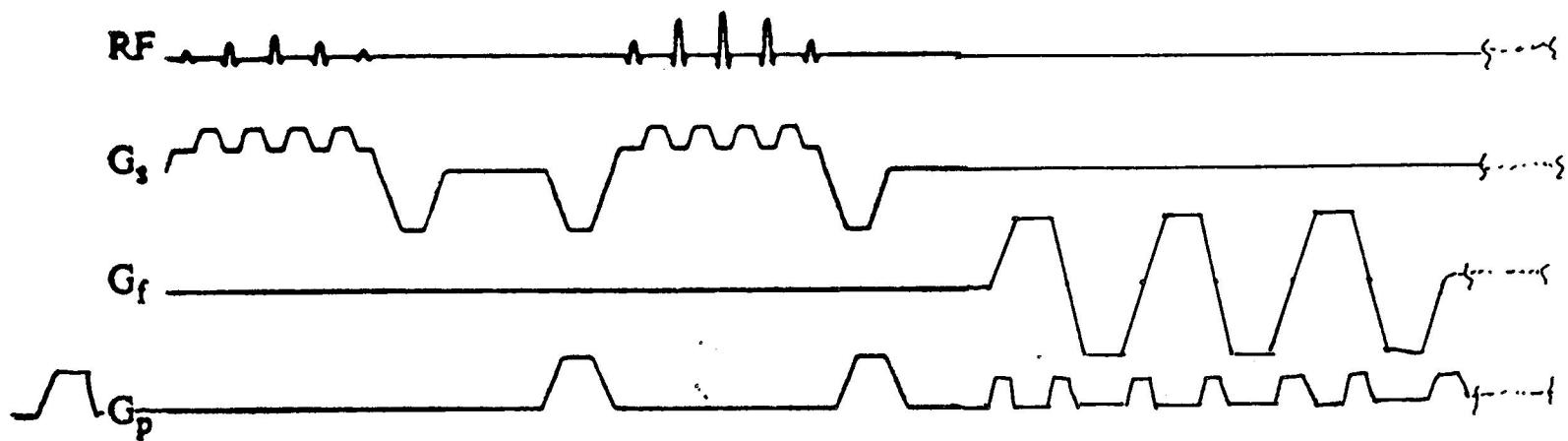
aceto.M

100%

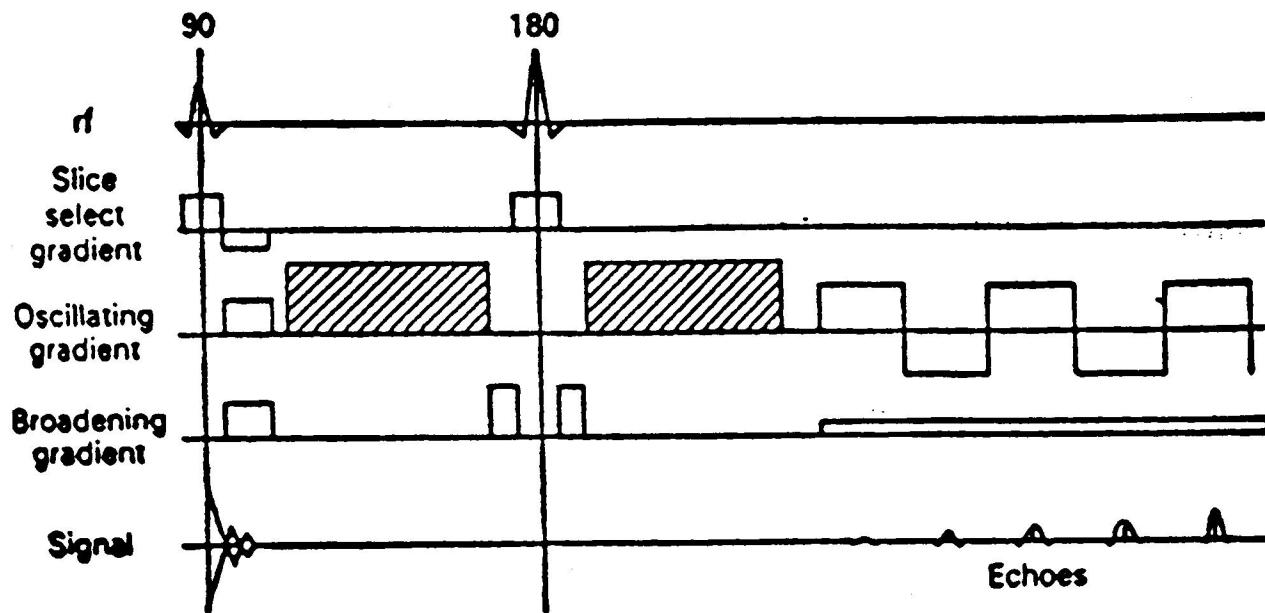
7
1
4

0

Eric's Perfusion Sequence w/ EPI



Turner's Diffusion EPI sequence



High Temporal Resolution Dynamic Susceptibility-Contrast Imaging In The Brain

Premise: •Local alterations in neuronal activity during task performance, etc. cause changes in cerebral perfusion.

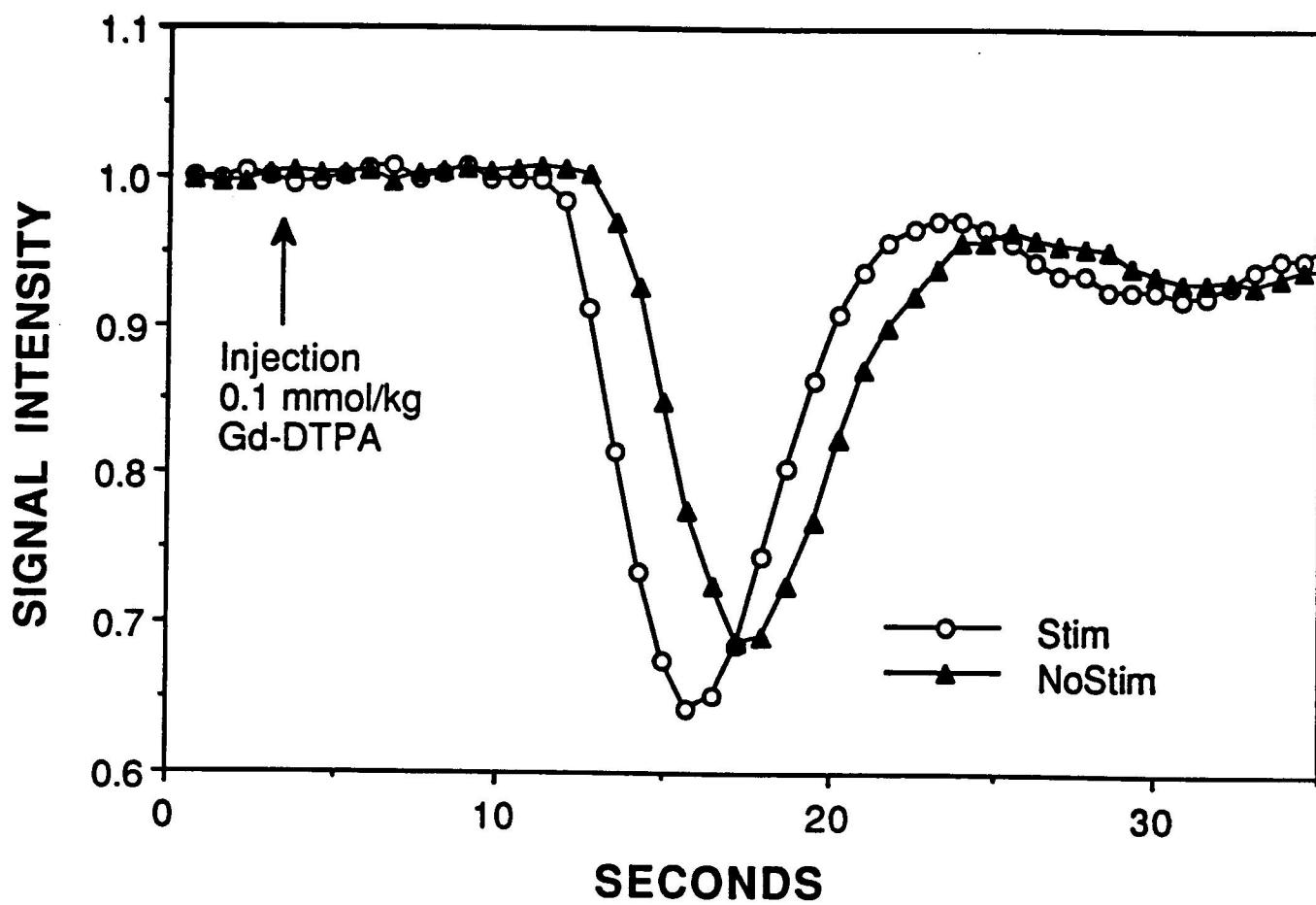
Method: •Person performing specific task.
•Gd-(DTPA)²⁻ injected simultaneously with EPI scanning.
•Slice thickness: 7 - 10 mm.
•Resolution: 3x3 mm.
•750 msec per scan (EPI).

- Theory:**
- Gd-(DTPA)²⁻ perfusion causes initial attenuation of signal due to susceptibility effects (micro-magnetic field inhomogeneities which cause spin dephasing)
 - Different rates and amounts of perfusion cause different characteristic attenuation due to Gd-(DTPA)²⁻ perfusion
-

***Functional Maps Created**

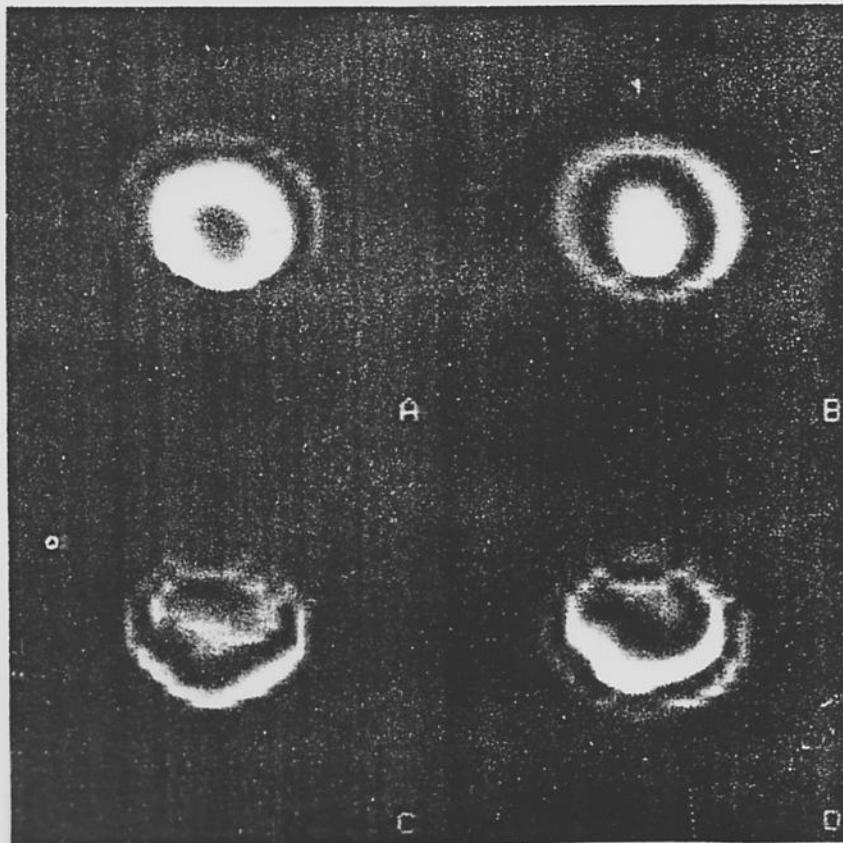
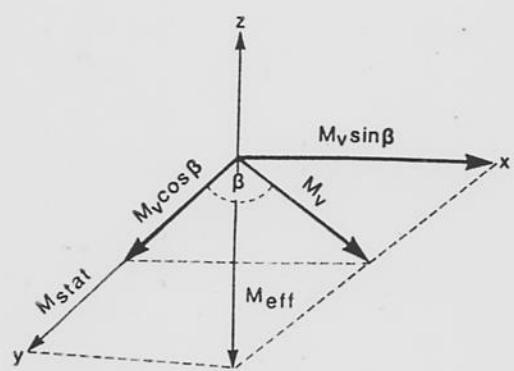
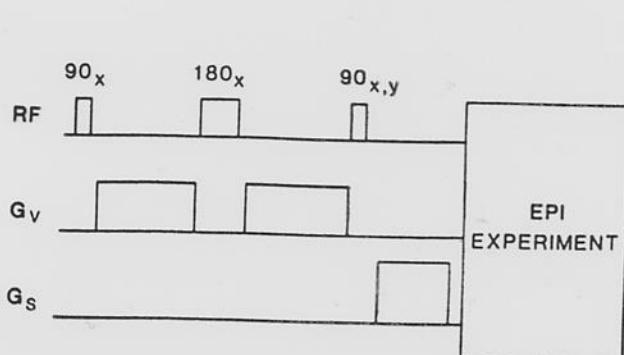
****For this type of study, it is better than PET, which has less spatial (10 - 18 mm) and temporal (5 - 20 min) resolution.**

NMR signal intensity changes in an ROI within visual cortex during rest (dark) and during stim (light).

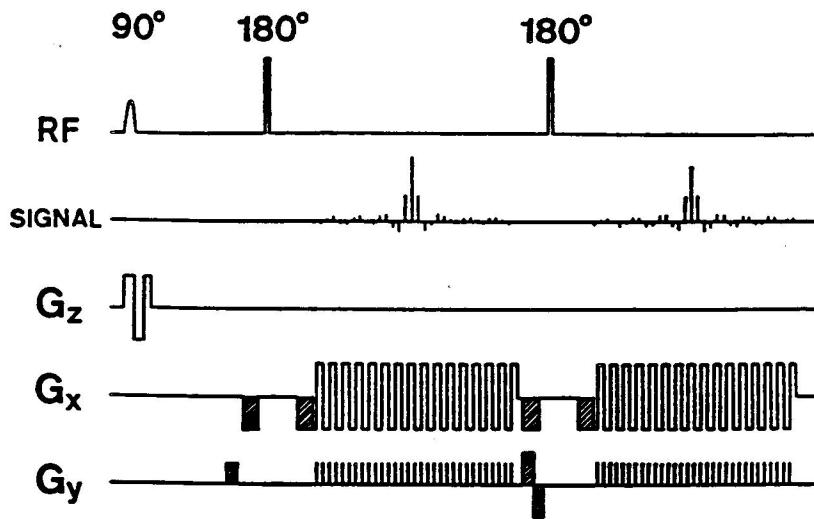


**The stimulated state has larger blood volume(area)
and shorter mean transit time (width)**

Method developed by Guilfoyle, Gibbs, Ordidge, and Mansfield to Instantaneously Image Laminar and Turbulent Flow



Kose's Method of Instantaneously Mapping Laminar and Turbulent Flow



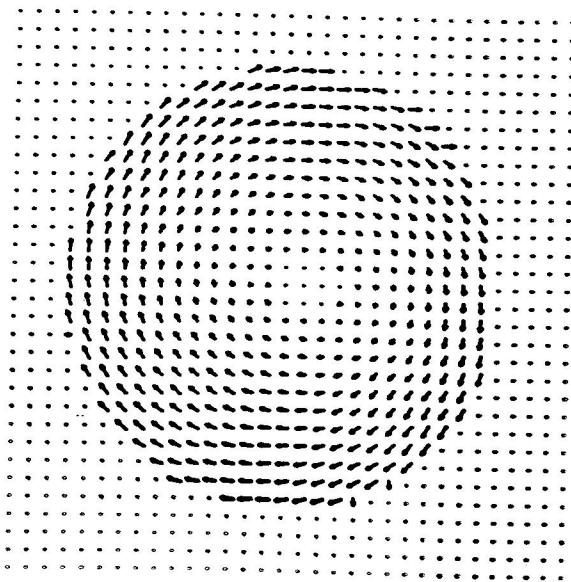
$$\alpha = 4.5 \text{ rad/cm/sec.}$$

$$\Delta\phi_1 = \alpha_1 v_x + \beta_1 v_y$$

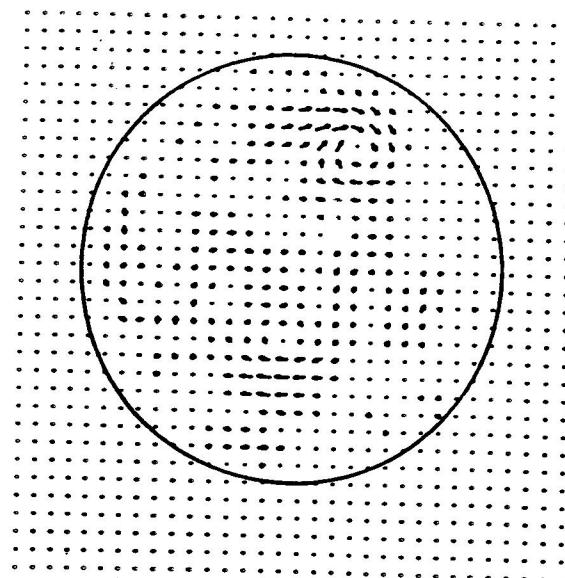
$$\beta = 0.5 \text{ rad/cm/sec.}$$

$$\Delta\phi_2 = \alpha_2 v_x + \beta_2 v_y$$

[determined using rotating phantom]



Laminar



Turbulent

EPI Directions to Pursue

- **Functional dynamic-susceptibility Imaging with flat gradient coils.**
- **General EPI pulse sequence development.**
 - Resolution, speed and/or image quality improvement.
 - New pulse sequences: advantages or disadvantages of particular k-space paths.
 - Extract chemical shift artifacts.
 - Theory of EPI.
 - Simulation of all EPI parameters.
- **Image Processing Development**
 - Cardiac cycle reordering.
 - Uses of large image sets.
 - Nonlinear K-space path interpolation methods.
 - Wavelet transform fast imaging.
 - Adaptive phase correction algorithm.
- **Real time flow/perfusion/diffusion or motion imaging.**
 - With flat or regular gradient coils.
 - Phase mapping in three dimensions.
 - Turbulent flow investigation.
- **Functional brain imaging with perfusion sequence without contrast agents.**